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RELATIONSHIP OF HOT HARDNESS TO ELEVATED TEMPERATURE MECHANICAL PROPERTIES

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S. V. GLORIOSO

23 DECEMBER 1960

ENGINEERING DEPARTMENT

CONVAIR FORT WORTH CONVAIR DIVISION GENERAL DYNAMICS CORPORATION

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CONVAIR FORT WORTH CONVAIR DIVISION GENERAL DYNAMICS CORPORATION

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Facilities Design and
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REPORT ABSTRACTS

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REPORT TITLE. Relationship of Hot Hardness to Elevated Temperature Mechanical Properties.

AUTHOR: S. V. Glorioso

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The possibility that the same method would apply to a correlation of hot hardness with brazed joint strengths was investigated. It was found that the macrohardness test used in this work could not be applied to the determination of brazed joint strength.

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S. V. Glorioso

SUMMARY

A method is described by which tensile and long time creep properties may be correlated to hot hardness. The procedure was used on PH15-7MO - RH950 and Rene' 41. The tensile and creep rupture properties were plotted against the parameter $P = T\ (C + \log t)$ with values for the constant C of 18 or 20. A similar plot or hardness was made against the parameter P. Cross plotting the curves obtained yielded a straight line, which indicated the existence of a valid correlation.

The possibility that the same method would apply to a correlation of hot hardness with brazed joint strengths was investigated. It was found that the macrohardness test used in this work could not be applied to the determination of brazed joint strength.

Introduction:

The evaluation of heat and corrosion resistant materials for structural applications in modern high speed aircraft and missiles includes elevated temperature mechanical testing. A useful correlation between hot hardness values and these mechanical properties would make it possible, through screening of materials, to reduce the amount of testing now required to obtain these properties.

The present means of evaluating experimental brazing alloys is expensive and time consuming. The mortality rate in specimen preparation is high and strength results obtained are scattered. Hot hardness, if applicable, would provide a quick screening method for the evaluation of brazing alloys.

Every standard hardness test available has been employed at elevated temperatures by other investigators. Determinations and tests range from testing a hot specimen with an unheated indenter at room temperature to various refined methods.

Hot hardness tests are being used for the following:

1) To indicate the upper limit of usefulness of a particular alloy

2) To indicate phase changes with temperature by changes in hardness

3) To indicate the optimum temperature range for hot working

4) To screen materials with respect to stress rupture properties.

Object:

The objects of the test were as follows:

1. To construct a hot hardness tester and to evaluate techniques for hot hardness determinations at temperatures up to 1800 F.

2. To establish the relationship of hot hardness with other elevated temperature properties for Rene' 41 and PH15-7 MO.

3. To investigate the possibility that a relationship of hot hardness with brazed joint strengths of A 286 exists.

Procedure:

A literature survey on hot hardness test methods and correlations between hot hardness and mechanical properties was made. Other investigators (1, 2, 3) have reported a correlation of hot hardness with stress rupture properties. No literature was found in which hot hardness was correlated to brazed joint strength.

Of the many hardness tests available, the Vicker's pyramid hardness test was chosen for this investigation for the following reasons:

1. Our main interest is in the properties of sheet materials; therefore, a test which does not penetrate too deeply into the specimen was needed.

2. The requirement that a large number of hardness determinations could be made on a small sample was satisfied by the small indentation of the Vicker's test.

3. The Vicker's test is practically independent of the load applied. Since the alloys of interest in this investigation are very soft at elevated temperatures, it was necessary to use a lower load than is employed with standard hardness tests.

A Wilson superficial hardness tester was used for load application. This machine was modified to provide a total indenting load of 4.6 kg. Hardness values were obtained with the following relationships:

$$\text{DPHN} = 1.8544\frac{(L)}{d^2} \text{ where } L \text{ is } 4.6$$

kgm and d is the length of the diagonal of the indentation in millimeters. Diagonals were measured at room temperature on a Tukon microhardness tester. The error from thermal expansion which resulted from making the impression at elevated temperatures and subsequently measuring the indentation at room temperature was neglected. Fredrick P. Bens (1) calculated this error on copper indented at 1700 F and found it to be 2DPHN hardness points. Copper was chosen because of its high coefficient of expansion and low hardness which produced a greater magnitude of error than would be found in most materials.

A nichrome-wound resistance furnace was used for heating. An Inconel X extension for the indenter and anvil position the specimen in the center of the furnace. The indenter extension was water cooled at the top of the furnace.

An adjustable stage shifted the specimen with respect to the indenter permitting the placement of 32 indentations on a specimen 1" x 1/2", as shown in Figure 1, without cooling the furnace. Argon (10 cfh) with a dew point of approximately -100 F provided adequate protection of the specimen from oxidation. A temperature survey indicated that the temperature on top of the anvil and on the specimen were identical. Temperature was measured with a chromel-alumel thermocouple mounted permanently on the anvil. The side of the specimen on which the indentations were to be made was handpolished using standard metallographic practices. The opposite side was ground through 0 emery paper. The indenters were sapphire mounted in Inconel X. A sapphire instead of a diamond was used because other investigators report that the diamond did not give adequate service above 1300 F. F. Garofalo, P. R. Malenock and G. V. Smith[2] report that after a dozen or so impressions at 1500 F on steels, a portion of a diamond indenter tip which penetrated the test material began to show signs of disintegration. The indenter tip seemingly dissolved away leaving an irregular or zagged, truncated surface. No such problem occurred with sapphire.

Through correspondance with E. E. Underwood at Battelle Memorial Institute, Columbus, Ohio, it was learned that F. F. Gilmore and Company, Boston, Massachusetts supplied Battelle with suitable sapphires for hot hardness testing to 2000 F. Under this program, Convair purchased sapphire indenters from F. F. Gilmore and Company for $42 each.

The hardness tester was checked at room temperature on a standard Rockwell test block (Rockwell "C" - 26.9). Vicker's pyramid hardness measurements made with the hardness tester were equivalent to Vicker's pyramid hardness measurements made on the same block with a Tukon microhardness tester and converted favorably to Rockwell "C" using conversion charts for steel.

A photograph (Figure 2) and a schematic drawing (Figure 3) show the essential parts of the furnace and hardness tester.

The following procedure was used for taking hardness measurements: the bottom stage was slowly raised. The needle on the hardness tester dial, see Figure 2, moved when the indenter contacted the specimen. The stage was raised until this needle made 3 revolutions. The lever on the tester was then tripped, which started the loading mechanism through a dash pot. As soon as the load was applied the needle rotated and the time of indentation was started. To unload the specimen, the lever on the tester was pulled forward. The

stage was then lowered through the screw jack and adjusted for the next reading.

Hot hardness readings were taken on PH15-7MO RH950 at temperatures to 1100 F at various times up to 2000 seconds and on Rene' 41 at temperatures to 1800 F at 10 second indentation times.

For brazed joint evaluations, specimens were prepared with one layer of brazing alloy foil on A-286 base material, so that the brazing alloy melted and flowed on the base metal. The brazing alloy was Coast 1700 - Co, Ni which had a nominal composition as follows: 63% Cu, 22% Mn, 10% Co and 5% Ni. Specimens were brazed at 1900 F for 5 minutes. The brazing alloy surface was lightly polished and hardness readings were taken on the flatest portion. It was found that at higher temperatures, the indenter penetrated into the base metal giving high values for hardness. Specimens were then prepared with three layers of brazing alloy foil to yield a thicker brazed zone. Hardness readings were taken on these specimens at temperatures to 1300 F at various times up to 30 minutes.

Thirty six AWS lap shear specimens as shown in Figure 4, were brazed for tensile and sustained load tests. The same braze cycle was used as stated above for the hot hardness specimens.

Brazed joint specimens were tested on a 5000 lb. Baldwin Universal Test Machine according to the following schedule:

Test Temperature	Number of Specimens
R.T.	3
1000 F	3
1100 F	3
1200 F	3
1300 F	3

Heating was accomplished with Marshall furnaces. Twenty-one specimens were sustained load tested on Arcweld creep rupture machines at temperatures from 1050 to 1300 F.

Ten hot hardress specimens were prepared with different experimental brazing alloys on niobium. The ultimate strength of joints with these alloys at 2000 F had been determined in other work. Hot hardness was taken at 2000 F on each of these specimens.

Results:

The hot hardness determinations on PH15-7 MO RH950 and Rene' 41 sheet are tabulated in Tables I and III. Tensile and stress rupture data for these alloys obtained from the literature is included in Table II and IV. These results are shown graphically in Figures 5 through 10.

The hot hardness determinations and tensile and sustained load results for brazed A-286 are given in Table V and VI and Figure 11.

The following hot hardness and ultimate strength values were obtained for experimental brazing alloys on niobium:

Brazing Alloy	Test Temp F	Hot Hardness DPHN	Ultimate Strength PSI
Ti Base	2000	54	6,120
" "	"	Below 29	5,090
" "	"	73	12,310
" "	"	23	5,990
Cr Base	"	(1)	10,400
" "	"	(1)	8,090
Ti-Cr Base	"	87	7,310
" "	"	41	9,050
" "	"	49	5,900
" "	"	39	4,410

(1) Constituent in brazing alloy melted at 2000 F obscuring impression.

Discussion:

The following method was used to correlate hot hardness to stress rupture properties as described by E. E. Underwood (3). The hot hardness and stress rupture data are plotted against a time-temperature parameter, $P = T\ (C + \log t)$ developed by Larsen and Miller (4) where T is the absolute temperature in °R, t is a measure of the test time in hours and C is a material constant. The constant, C, can be calculated as follows from stress rupture data at the same stress but different temperatures. The parameter is constant at a given stress:

P_1 = parameter value at T_1 and t_1

P_2 = parameter value at T_2 and t_2

Where t_1 is time to failure at T_1 and t_2 is time to failure at T_2. T_1, t_1, T_2, and t_2 are known quantities.

$$\overset{P_1}{T_1(C + \log t_1)} = \overset{P_2}{T_2\,(C + \log t_2\,)}$$

The constant was found to be approximately 20 for various materials investigated by Larsen and Miller.

The time of the tensile test was arbitrarily taken as 3 minutes. Since the log t is small compared to C = 20, any error in this assumption would be negligible. The tensile, stress rupture and hot hardness data are plotted against the parameter P, see Figures 6 and 9. Two features are evident; the creep and tensile data fall on the same curve and the hardness curve parallels the strength curve. The data fall along two straight lines intersecting at a point known as the equicohesive temperature (5). The grain boundaries are a source of strength below this temperature and a source of weakness above this temperature. The constant C was adjusted slightly so that the break off points for the hot hardness and tensile and stress rupture curve fall at the same value of the parameter P. This occurred at $P = 24.0 \times 10^{-3}$ for PH15-7 MO RH950 (see Figure 6) with C = 20 for tensile results, 18 for stress to rupture and 20 for hot hardness. For the Rene' 41 the breakoff points occurred at $P = 33.5 \times 10^{-3}$ as shown in Figure 9 with C = 18 for the tensile and creep rupture data and 20 for hot hardness. The curves were then cross plotted to give the hardness strength correlation for PH15-7 MO (Figure 7) and Rene' 41 (Figure 10).

From the experimental results obtained on hot hardness versus brazed joint strength, the hardness test would not appear to be an adequate screening procedure for brazing alloys. The results on niobium brazing alloys yielded no correlation between hardness and joint strength; however, the joint strength values were from single specimens and can not be considered accurate. The miltiple specimen lap shear data on A286 gave considerable scatter, but an estimate of the equicohesive temperature might be derived from this data. For a braze alloy layer of normal thickness an A-286, no equicohesive temperature could be established from hardness values. With the test load being used, the braze alloy was penetrated at high temperatures and the base metal affected the hardness value. With an abnormally thick alloy layer the hardness results were also questionable because of the effect of base metal (Figure 12). The location of the equicohesive temperature on a plot of this data was indefinite. It would be impractical to use a thicker alloy layer because the effects of diffusion of base metal into the alloy would be obscurred. Indents made with a smaller load might yield useable information. In general, the joint strength appears

to be influenced by many factors, and, at best, only a rough estimate of this quantity could be obtained from hot hardness values.

Conclusions:

1. A hot hardness test machine was built which tests to 2000 F.

2. A strength-hardness correlation for Rene' 41 and PH15-7MO RH950 was determined.

3. No strength-hardness correlation was found for brazed joints.

Bibliography:

1. Bens, F. P., "Hardness Testing of Metals and Alloys at Elevated Temperatures," Trans. AM Soc. Metals 38, p 505-516, 1947.

2. Garofalo, F., Malenock, P. R., and Smith, G. V., Trans. Am. Soc. Metals 45 p 377-396, 1953.

3. Underwood, E. E., Marsh L. L. and Manning, G. K., "The Principles of Dispersion Hardening Which Promote High Temperature Strength in Iron - Base Alloys," WADC Technical Report 56-184, October 1957.

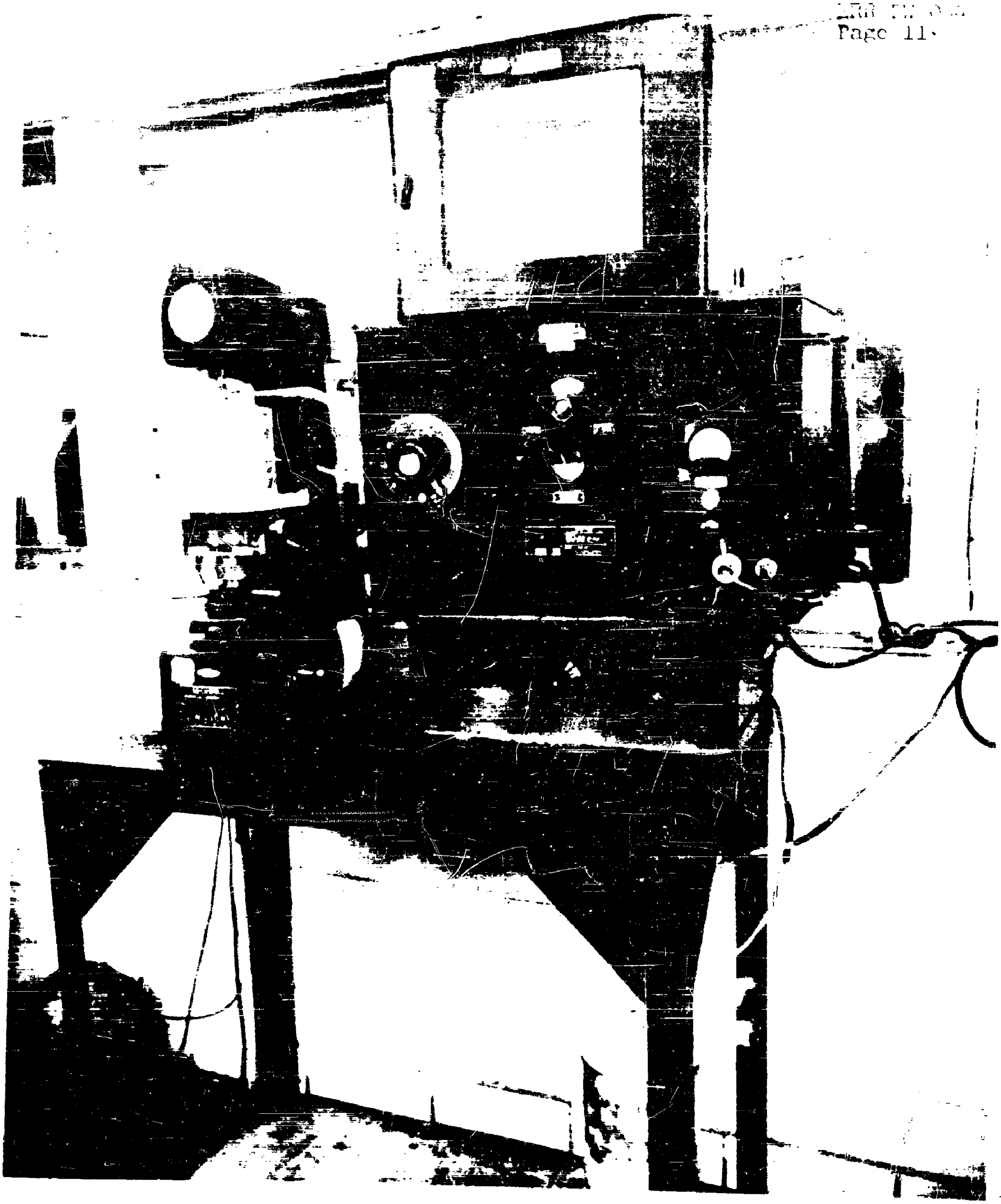
4. Larson, F. R., and Miller, J., Trans. ASME, 74 p 765 (1952).

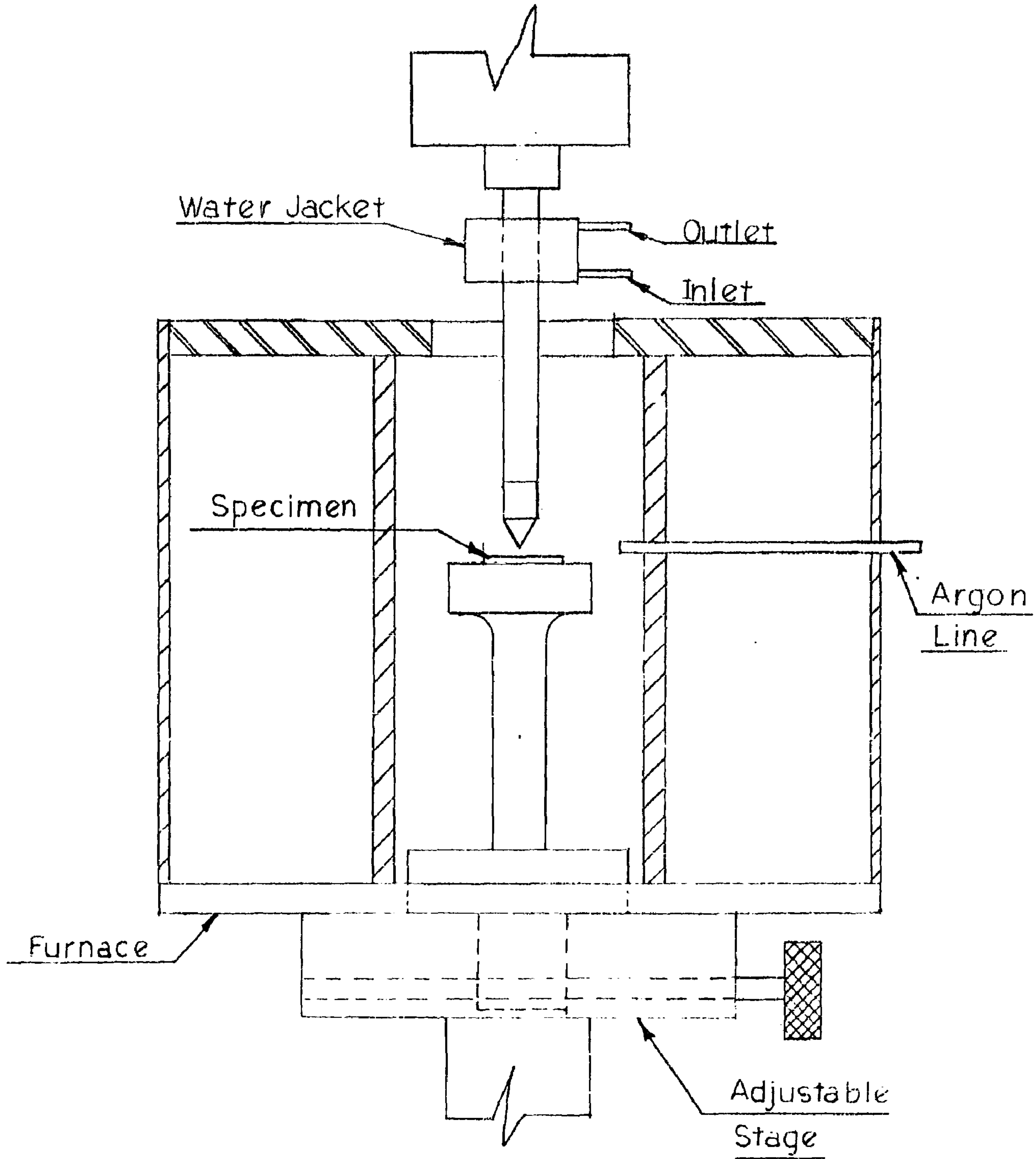
5. Gensamer, M., "The Effect of Grain Boundaries on Mechanical Properties," Am. Soc. Metals Seminar, Relation of Properties to Microstructure, Cleveland, 1954, 16.

Indentations shown below at higher magnification.

5X Each Division is 1/32"
Photograph showing Rene' 41 specimen with hot hardness indentations.

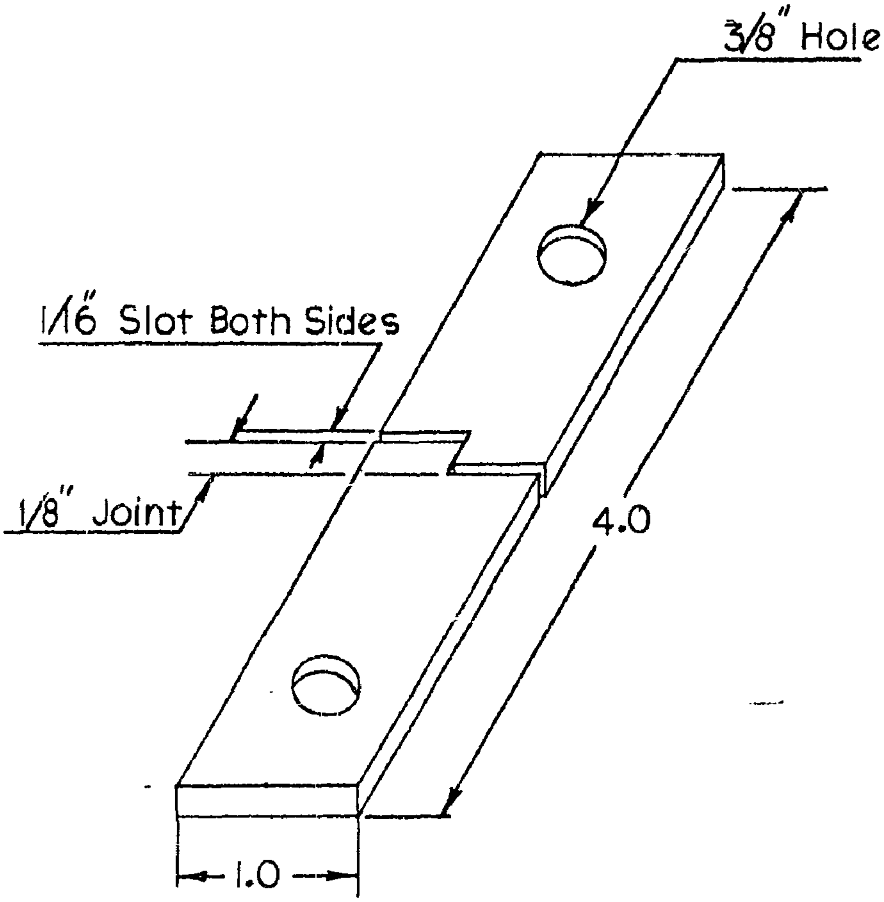
FIGURE 1





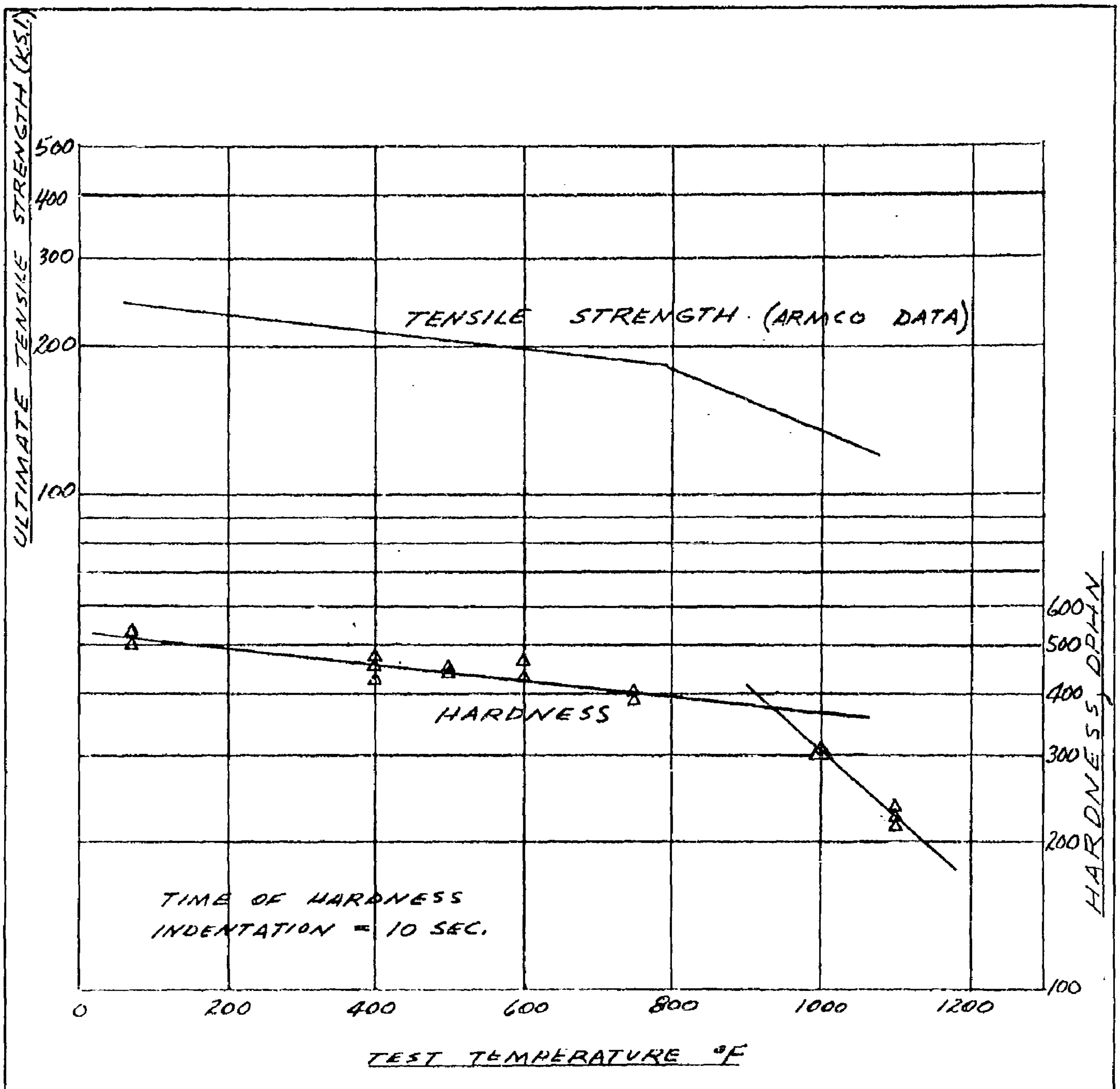
SCHEMATIC SHOWING ESSENTIAL PARTS OF HARDNESS TESTER

FIGURE 3



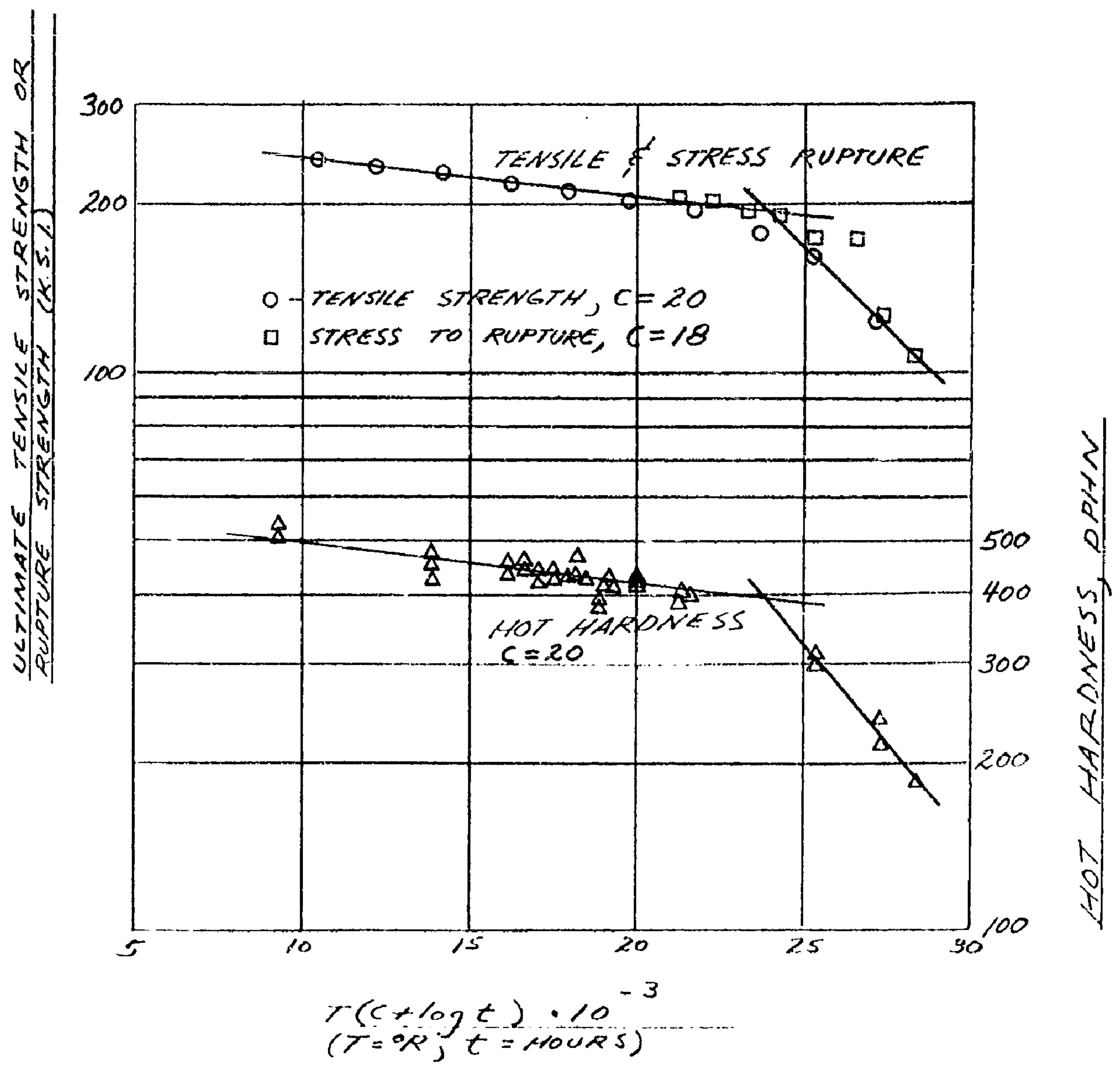
SPECIMEN FOR DETERMINATION OF BRAZED JOINT STRENGTH

FIGURE 4



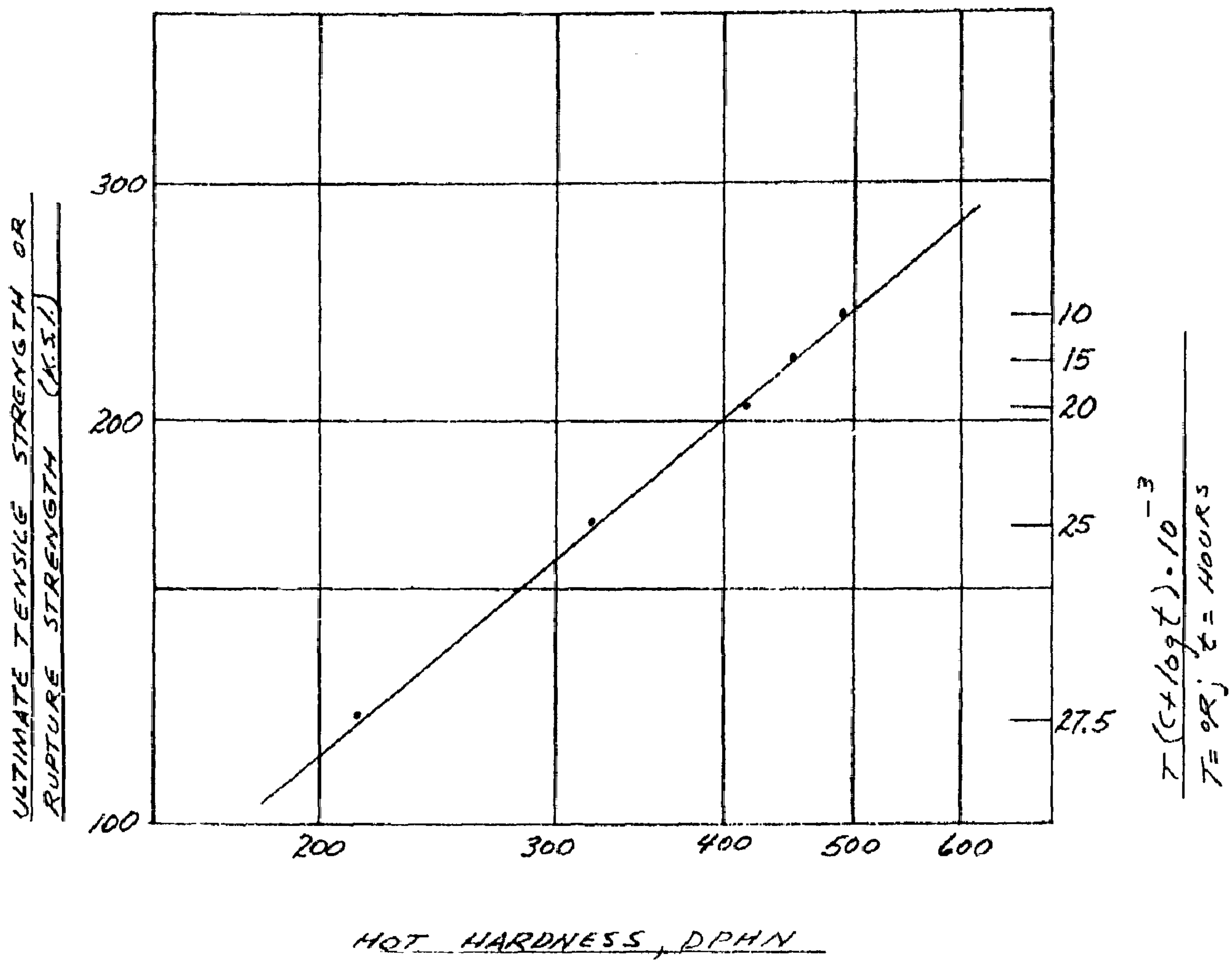
TENSILE STRENGTH AND HARDNESS AS A FUNCTION OF TEMPERATURE FOR PH 15-7 MO RH 950

FIGURE 5



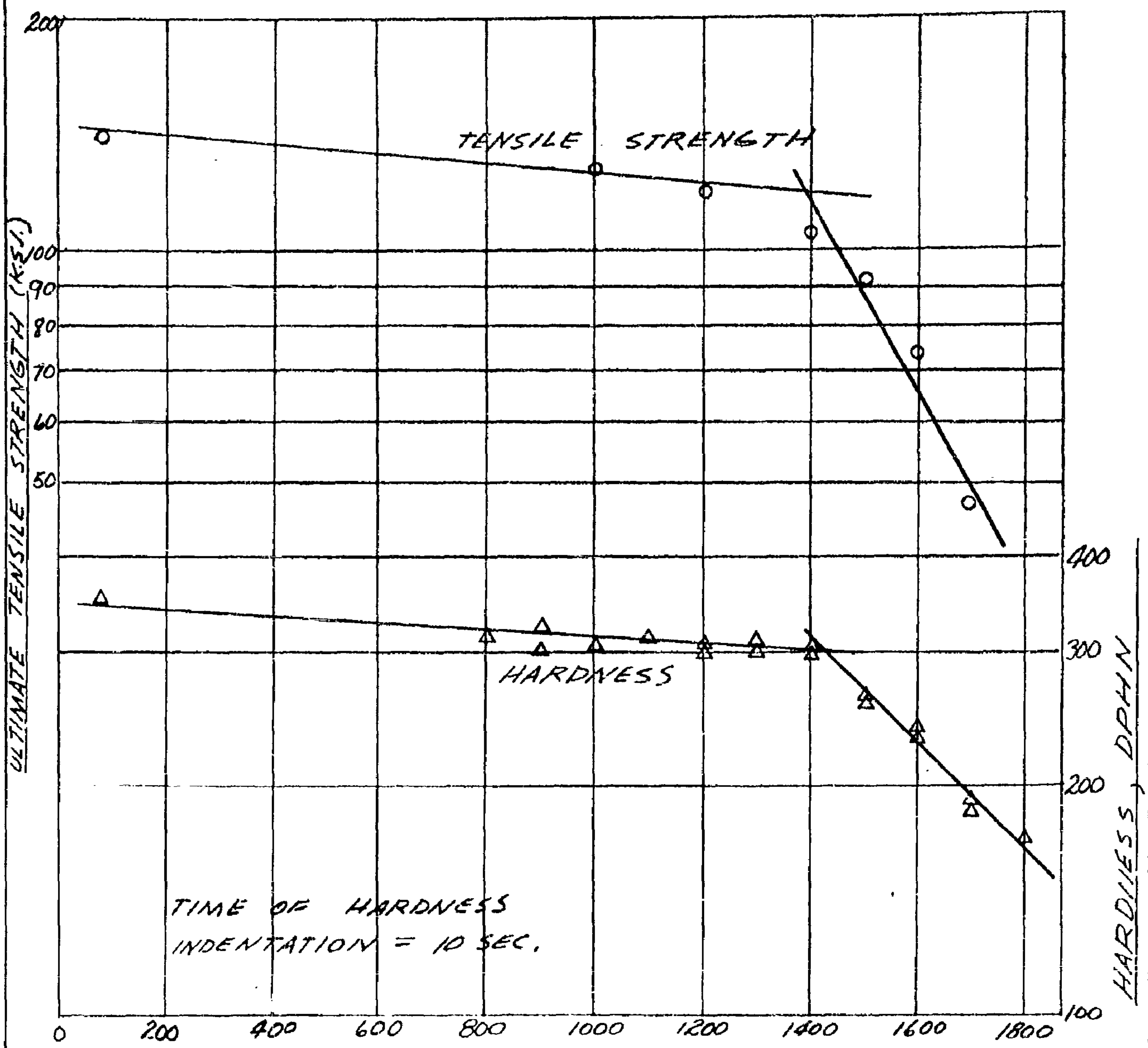
RELATION OF TENSILE AND STRESS TO RUPTURE TO HOT HARDNESS OF PH 15 7 MO AM350 WHEN PLOTTED VERSUS TIME - TEMPERATURE PARAMETER

FIGURE 6



STRENGTH HARDNESS CORRELATION
FOR PH15-7MO RH950

FIGURE 1

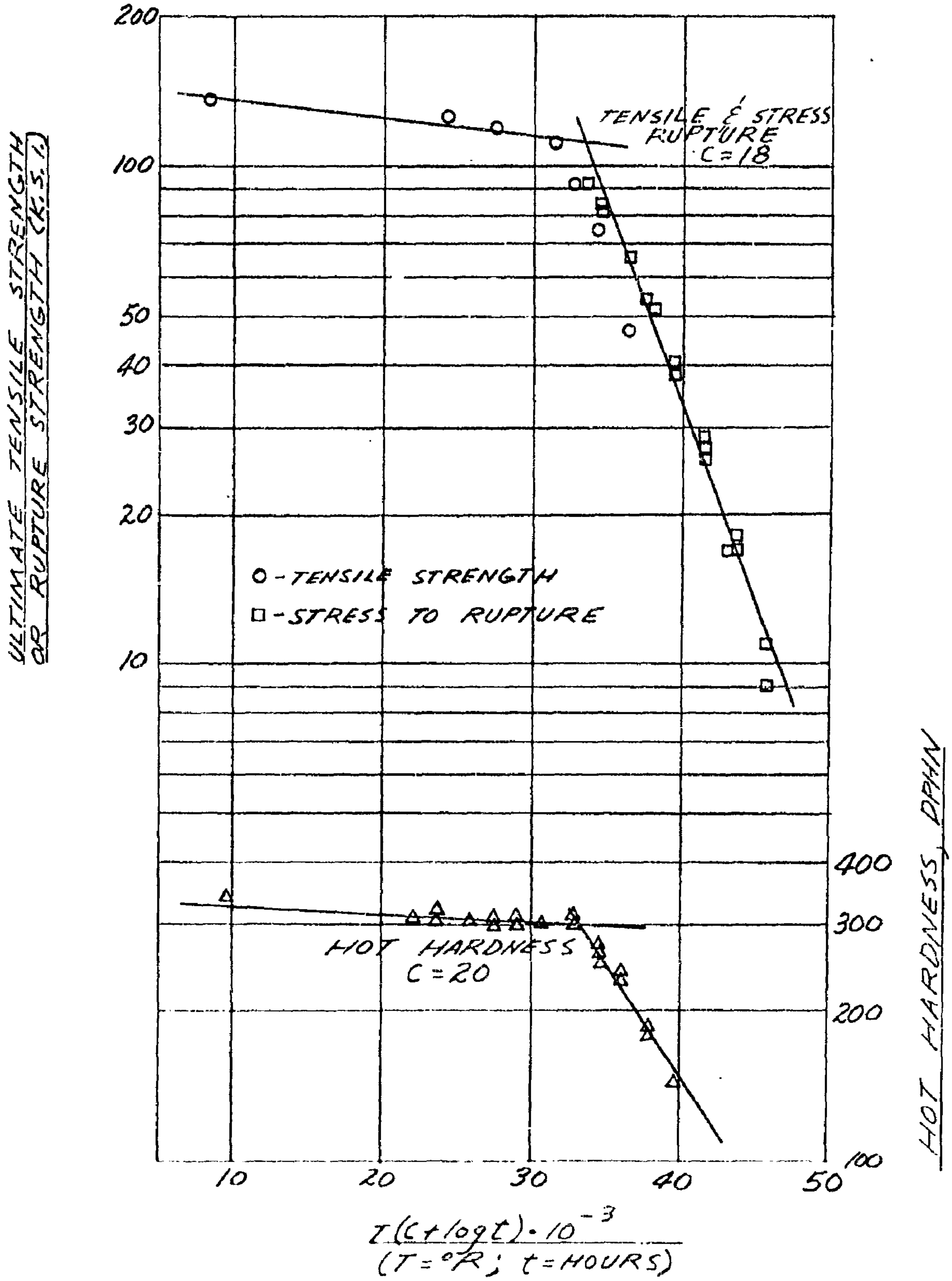


TEST TEMPERATURE °F

HT. TREATMENT - 2150 F - 12 MIN. - AIR COOL - AGE 1650 F - 4 HOURS - AIR COOL

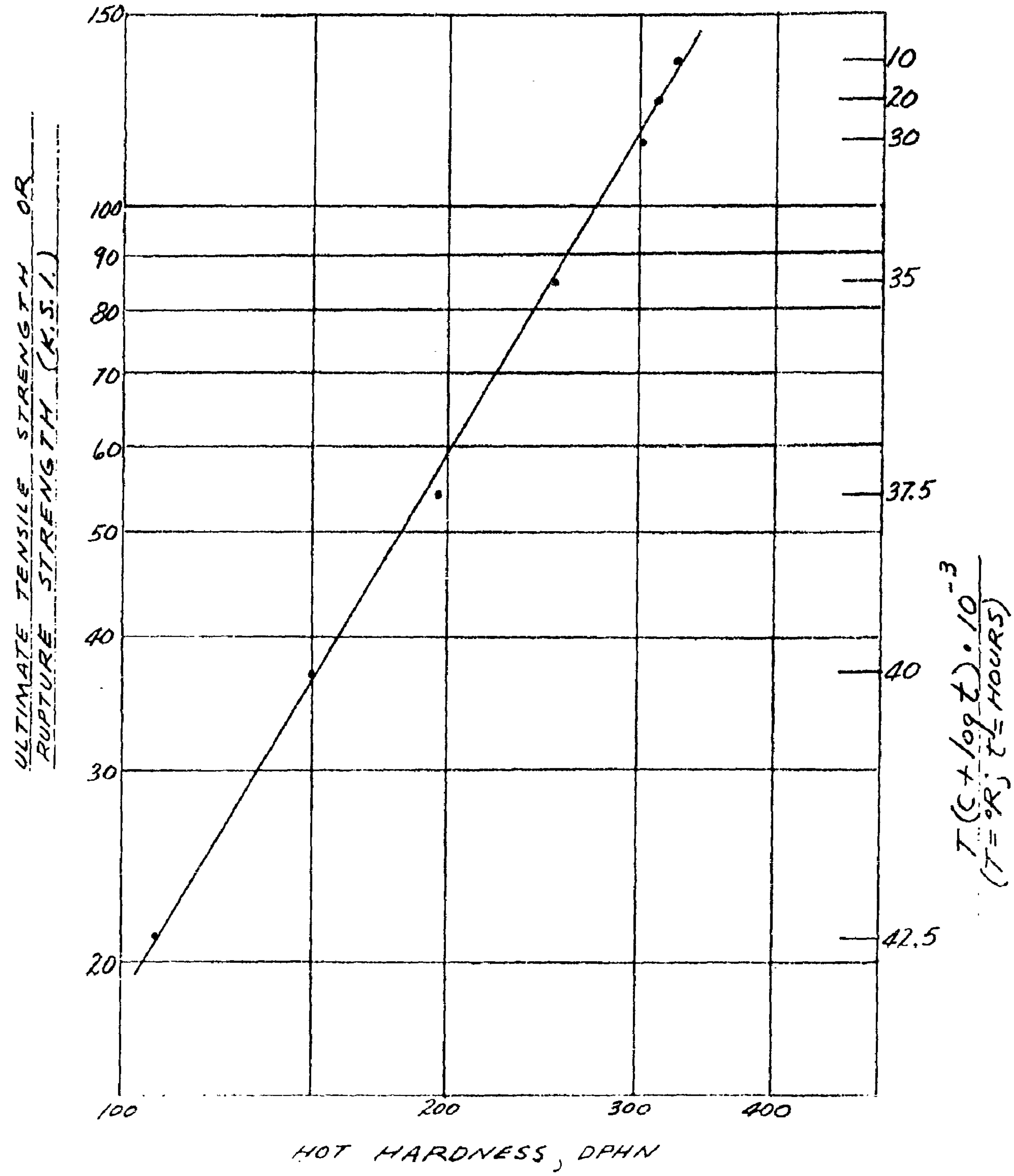
TENSILE STRENGTH AND HARDNESS AS A FUNCTION OF TEMPERATURE FOR RENE '41

FIGURE 8



RELATION OF TENSILE AND STRESS TO RUPTURE TO HOT HARDNESS OF RENE' 41 WHEN PLOTTED VERSUS TIME-TEMPERATURE PARAMETER

FIGURE 7



STRENGTH HARDNESS CORRELATION
FOR RENE' 41

FIGURE 10

TABLE I

HOT HARDNESS DATA FOR PH15-7MO RH950

SHEET - .032 GAGE

TEST TEMP F	TEST TEMP R	HARDNESS, DPHN	$T(C+\log t)\cdot 10^{-3}$ $T=°R;\ t=HOURS;\ C=20$
78	538	540	9.4
"	"	503	"
400	860	420	13.8
"	"	460	"
"	"	464	"
500	960	440	16.6
"	"	450	"
600	1060	432	18.3
"	"	464	"
750	1210	389	21.1
"	"	394	"
1000	1460	309	25.4
"	"	308	"
"	"	308	"
1100	1560	235	27.2
"	"	224	"
"	"	217	"

TIME OF HARDNESS INDENTATION = 10 SEC.

TEST TEMP. F	TEST TEMP. R	HARDNESS, DPHN	INDENTATION TIME SEC.	$T(C+\log t)\cdot 10^{-3}$ $T=°R;\ t=HOURS;\ C=20$
400	860	440	60	16.1
"	"	433	"	"
"	"	454	"	"
"	"	454	1000	16.6
"	"	432	"	"
"	"	445	"	"
"	"	436	2000	17.0
"	"	445	"	"
"	"	441	"	"
500	960	432	60	17.5
"	"	440	"	"
"	"	436	"	"
"	"	428	1000	18.5
"	"	374	2000	18.9
"	"	381	"	"

TABLE I CONTD.

HOT HARDNESS DATA FOR PH15-7 MO - RH950

SHEET - .032 GAGE

TEST TEMP. F	TEST TEMP. R	HARDNESS, DPHN	INDENTATION TIME SEC	$T(C+\log t)\cdot 10^{-3}$ T=°R; t=HOURS; C=20
600	1060	391	30	19.0
"	"	419	"	"
"	"	423	45	19.2
"	"	407	"	"
"	"	402	60	19.3
"	"	395	"	"
"	"	399	"	"
"	"	411	300	20.0
"	"	407	"	"
"	"	423	"	"
700	1160	399	60	21.5
1100	1560	185	60	28.4

TABLE II (ARMCO DATA)

SHORT TIME TENSILE PROPERTIES FOR PH15-7MO RH950

TEST TEMP F	TEST TEMP R	ULTIMATE STRENGTH KSI.	$T(C+\log t)\cdot 10^{-3}$ T=°R; t=.05 HOURS; C=20
100	560	240	10.5
200	660	232	12.3
300	760	225	14.2
400	860	217	16.1
500	960	210	18.0
600	1060	202	19.8
700	1160	192	21.7
800	1260	177	23.6
900	1360	160	25.4
1000	1460	125	27.2

STRESS RUPTURE PROPERTIES FOR PH15-7MO RH950

TEST TEMP. F	TEST TEMP. R	STRESS KSI	TIME TO FAILURE HOURS	$T(C+\log t)\cdot 10^{-3}$ T=°R; t=HOURS; C=18
600	1060	202	100	21.2
700	1160	193	100	23.2
800	1260	174	100	25.2
900	1360	125	100	27.2
600	1060	200	1000	22.2
700	1160	191	1000	24.4
800	1260	171	1000	26.5
900	1360	108	1000	28.6

TABLE III

HOT HARDNESS DATA FOR RENE' 41

SHEET - 062 GAGE

TEST TEMP. F	TEST TEMP. R	HARDNESS, DPHN	$T(C+\log t)\cdot 10^{-3}$ $T=°R;\ t=\text{HOURS};\ C=20$
78	538	358	9.4
"	"	358	"
800	1260	316.	22.0
900	1360	304.	23.7
"	"	329.	"
1000	1460	308.	25.4
"	"	311.	"
1100	1560	308	27.2
"	"	312	"
"	"	313	"
"	"	315	"
1200	1660	311	29.0
"	"	300	"
"	"	304	"
1300	1760	311	30.7
"	"	308	"
1400	1860	300	32.4
"	"	308	"
1500	1960	280	34.2
"	"	257	"
"	"	256	"
"	"	263	"
"	"	257	"
1600	2060	240	36.0
"	"	236	"
1700	2160	188	37.7
"	"	176	"
1800	2260	142	39.4

TIME OF HARDNESS INDENTATION = 10 SEC.

HT TREATMENT - 2150 F - 12 MIN - AIR COOL - AGE 1650 F - 4 HOURS - AIR COOL

TABLE IV

SHORT TIME TENSILE PROPERTIES FOR RENE' 41

SHEET - .062 GAGE

TEST TEMP. F	TEST TEMP. R	ULTIMATE STRENGTH K.S.I.	$T(C+\log t)\cdot 10^{-3}$ $T = {}^\circ R$, $t = .05$ HOURS
70	530	140	8.9 C = 18
1000	1460	128	24.4
1200	1660	120	27.7
1400	1860	105	31.2
1500	1960	92	32.7
1600	2060	74	34.4
1700	2160	47	36.1

STRESS RUPTURE PROPERTIES FOR RENE' 41

SHEET - .062 GAGE

TEST TEMP. F	TEST TEMP. R	STRESS K.S.I.	TIME TO FAILURE HOURS	$T(C+\log t)\cdot 10^{-3}$ $T = {}^\circ R$; t = HOURS
1350	1810	82	10	34.4 C = 18
1500	1960	55	10	37.2
1600	2060	39	10	39.1
1700	2160	27	10	41.1
1800	2260	17	10	43.0
1200	1660	92	100	33.7
1350	1810	66	100	36.1
1500	1960	40	100	39.1
1600	2060	26	100	41.1
1700	2160	18	100	43.3
1800	2260	9	100	45.2
1200	1660	82	1000	34.9
1350	1810	52	1000	38.0
1500	1960	28	1000	41.2
1600	2060	17	1000	43.3
1700	2160	11	1000	45.4

HT TREATMENT - 2150 F - 12 MIN AIR COOL - AGE 1650 F - 4 HOURS - AIR COOL

DATA FROM KELSEY-HAYES COMPANY PAMPHLET - "UDIMET 41"

TABLE VI

ULTIMATE STRENGTHS FOR A-286 JOINTS BRAZED WITH COAST 1700 - CO, NI

TEST TEMP F	ULTIMATE STRENGTH KSI.
R.T.	35.3
"	47.6
"	48.5
1000	30.3
"	28.7
"	22.7
1100	13.2
"	15.6
"	17.6
1200	21.0
"	16.6
"	18.2
1300	9.9
"	5.9
"	7.2

STRESS RUPTURE PROPERTIES FOR A-286 JOINTS BRAZED WITH COAST 1700 - CO, NI

TEST TEMP F	STRESS KSI.	TIME TO FAILURE HOURS
1050	3.7	1078 (NO FAILURE - SPECIMEN UNLOADED)
1070	10.1	24.7
1100	6.9	.05
"	5.1	2
1050	8.0	14
1200	3.9	.25
"	3.3	8.4
"	3.8	.60
"	3.0	2.2
"	2.7	16.4
"	3.5	1130 (NO FAILURE - SPECIMEN UNLOADED)
"	6.0	.10
"	2.5	1000 (NO FAILURE - SPECIMEN UNLOADED)
"	3.0	1073 " " " "
1250	1.9	1024 " " " "
"	2.1	67
1300	1.2	65
"	1.6	2.5
"	1.5	762
1200	10.0	.10
"	5.0	1.7

SPECIMENS BRAZED AT 1700 F - 5 MINUTES

TABLE V

HOT HARDNESS DATA FOR A-286 JOINTS BRAZED WITH COAST 1700 - CO, NI

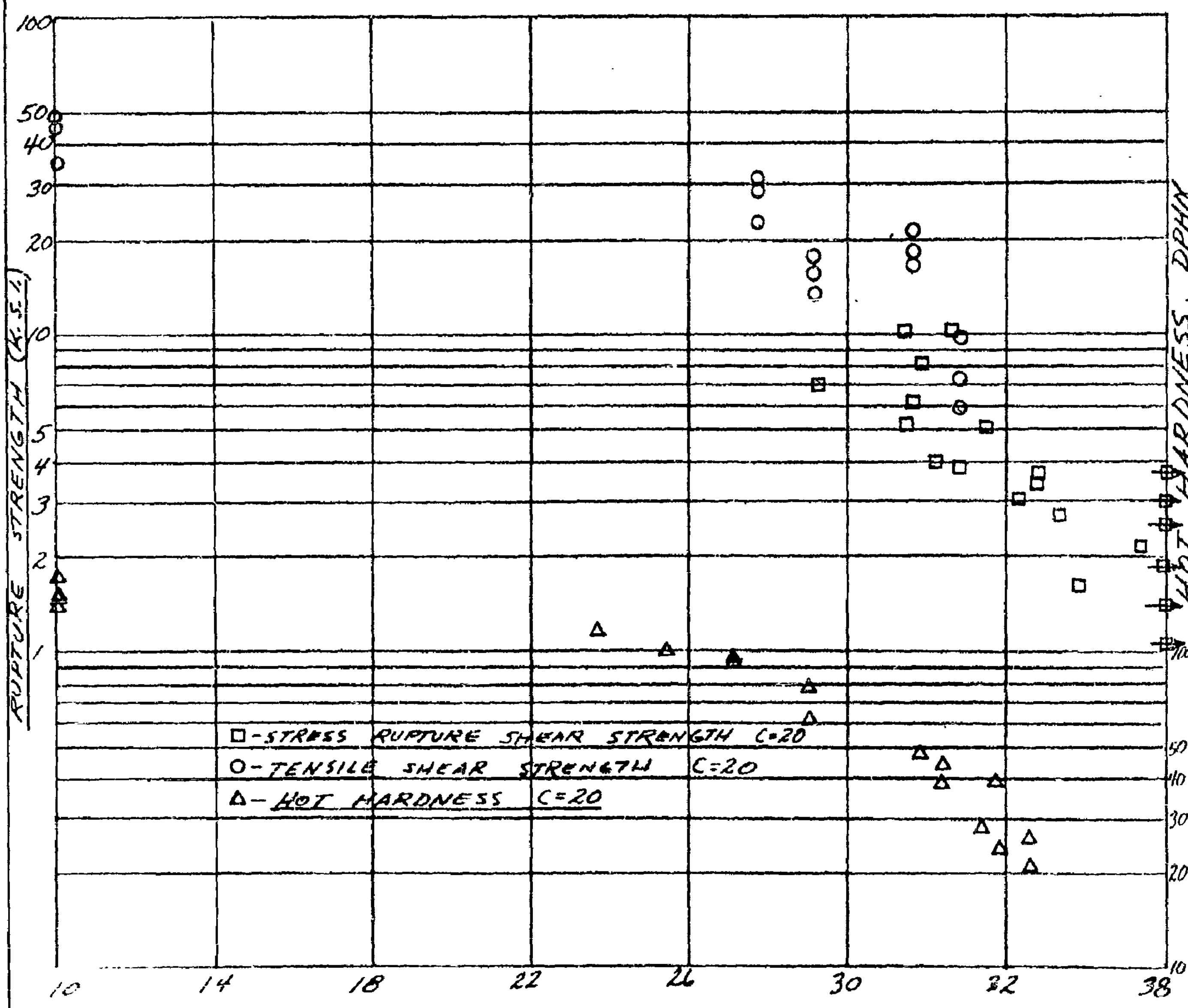
	TEST TEMP F	INDENTATION TIME SECONDS	HARDNESS DPHN
SPEC #1	78	10	157
	700	"	126
	900	"	118
	1000	"	116
	1100	"	114
SPEC #2	78	10	163
	"	"	164
	900	"	119
	"	"	121
	1000	"	113
	"	"	120
	1100	"	114
	"	"	114
	1200	"	108 (1)
	"	"	108 (1)
	"	"	109 (1)
	"	30	103 (1)
	"	"	110 (1)
	"	"	114 (1)
	"	60	105 (1)
	"	"	106 (1)
	"	"	107 (1)
	"	10 MIN.	105 (1)
SPEC #3	78	10	168
	1000	10 MIN	115
	"	"	109
	1200	10	114 (1)
	"	"	106 (1)
	1300	10 MIN	68 (1)
SPEC #4	78	10	156 (1)
	1000	10 MIN	116 (1)
	"	"	105 (1)
	1200	30 MIN	93 (1)
	1300	10 MIN	87 (1)

	TEST TEMP F	INDENTATION TIME SECONDS	HARDNESS DPHN
SPEC #5	78	10	170
	"	"	156
	1100	"	98
	"	"	96
	1200	"	77
	"	10 MIN.	48
	"	30 MIN.	38
	1300	10 MIN.	34
	"	6 MIN.	28
	"	30 MIN.	21
SPEC #6	78	10	150
	"	"	142
	900	"	119
	"	"	119
	1000	"	105
	1100	"	95
	1200	"	74
	"	30 MIN.	49
	1300	10 MIN.	44
	"	30 MIN.	28

(1) INDENTATION PENETRATED THROUGH BRAZE AND INTO BASE MATERIAL

SPECIMENS 1, 2, 3 & 4 BRAZED WITH ONE LAYER OF BRAZING ALLOY FOIL, SPECIMENS 5 & 6 WITH 3 LAYERS

SPECIMENS BRAZED AT [illegible] - 5 MINUTES.



SHEAR STRENGTH AND HOT HARDNESS FOR A 286 BRAZEMENTS VERSUS TIME TEMPERATURE PARAMETER

FIGURE 11